Gary Judd,[1] *Ph.D.; John Sabo,*[2] *B.S.; William Hamilton,*[3] *Ph.D.; Stark Ferriss,*[4] *B.A., J.D.; and Robert Horn,*[5] *B.S.*

SEM Microstriation Characterization of Bullets and Contaminant Particle Identification

Recent applications of the scanning electron microscope (SEM) have been in areas such as paint samples evaluation [*1,2*] and firing pin impressions [*3,4*]. These have provided useful additional information to the forensic scientist. This investigation was conducted to further expand the applicability of the SEM and the developed imaging techniques for use on other forms of physical evidence. Specifically, striations on copper-jacketed bullets and contaminant particles recovered from personal articles (clothing, shoes, etc) were chosen.

The primary objective of the bullet study was to determine if the SEM could provide an additional basis for striation comparison. The striations and microstriations along the shoulder of the land impression were investigated at a higher magnification than can be achieved through an optical examination of the bullets. The SEM allows this to be accomplished due to its great depth of field and high resolution.

Only a limited number of samples were chosen because the results of this study were planned to be used primarily for the determination of the feasibility of such an approach. The low magnification rifling markings have been independently well characterized by optical microscopy and the high magnification SEM analysis is essentially an extension of such techniques.

The object of the study of clothing contaminants was to determine whether or not SEM and its associated energy-dispersive X-ray analysis system (EDS) could provide an additional basis for the identification and comparison of small particulate contamination. The size, shape, topography, and elemental chemical composition may be determined in particles as small as a few micrometres (μm) (25 μm = 0.001 in.).

Individuals from a small number of diverse industrial job categories were chosen to test the feasibility of correlating the job environment with contaminants collected from the worker.

Received for publication 5 Feb. 1974; revised manuscript received 17 April 1974; accepted for publication 22 April 1974.

[1] Associate professor, Materials Division, Rensselaer Polytechnic Institute, Troy, N.Y.

[2] Formerly, graduate research assistant, Materials Division, Rensselaer Polytechnic Institute, Troy, N.Y.; presently, electron microscopist, New York State Police Scientific Laboratory, Albany, N.Y.

[3] Formerly, graduate research assistant, Materials Division, Rensselaer Polytechnic Institute, Troy, N.Y.; presently, research scientist, Litton Bionetics, Kensington, Md.

[4] Captain and director, New York State Police Scientific Laboratory, Albany, N.Y.

[5] Lieutenant and assistant director, New York State Police, Scientific Laboratory, Albany, N.Y.

Experimental Procedure

Bullet Striations

The markings on two sets of copper-jacketed bullets (listed below) were examined by the SEM.[6] Initially, the images were photographed at low magnification (×20–100) to orient the samples and to locate areas for examination.

Caliber	Type	Make	Serial Number
.38	auto	Llama	306211
.25	auto	Galesi	485370

A high magnification investigation was carried out on the striations and microstriations along the shoulder of the land impressions of each bullet of each set. Photomicrographs were taken along each of the striations to determine whether or not a consistent pattern of the microstriations was present. A topographical comparative study of the microstriations was then carried out with the aid of a comparative imaging system [5]. Photomicrographs were taken to record the images of each set of microstriations in the proper orientation.

Contaminant Particles

Particulate material was collected from industrial workers in the following job categories: (1) brass foundry worker, (2) brass grinding room worker, (3) iron machine shop worker, (4) iron melting department, (5) iron head treatment worker, (6) quarry foreman, (7) cement plant production worker, (8) cement plant office worker, (9) printing worker in a carton plant, and (10) materials handler in a board mill. The samples were collected by brushing or vacuuming clothing and shoes. The particles obtained were mounted with an adhesive silver paint and coated with carbon for conduction. They were examined by SEM and analyzed chemically by EDS.[7] The surface characteristics, size, and shape of the particles were determined in the SEM. X-rays from the particles were collected by the EDS. The X-rays were presented in a graphical form on an oscilloscope screen in the form of chemical element spectrum. The analysis of these data was then compared with the job classification for possible correlations.

Results and Discussion

Bullet Striations

Figure 1 shows a major land impression on a bullet fired from a .25 caliber Galesi pistol, as seen through an optical microscope. Figures 2*a* through 2*e* are a series of photomicrographs of the same area at increasing magnifications as seen by an SEM examination, with the highlighted region referring to the area shown in the next photomicrograph of the series. The increased magnifications show the detail obtainable through the use of an SEM caused by its greater depth of the field. Figure 3 shows a series of SEM photomicrographs taken from a bullet fired from a .38 caliber Llama

[6] Materials Analysis Corp. Model 700 scanning electron microscope.
[7] Nuclear Data Corp. Model ND812.

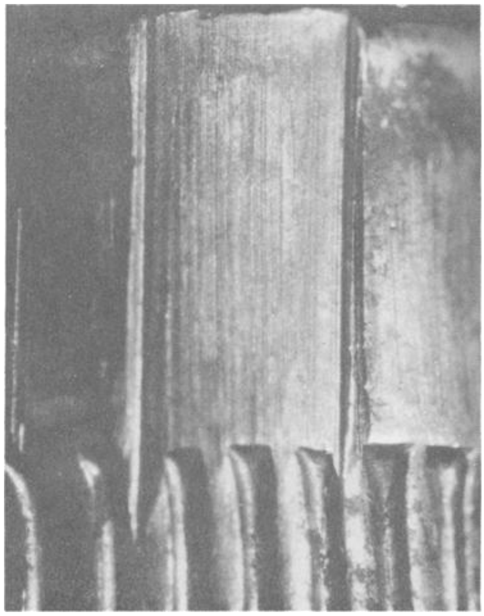

FIG. 1—*Optical microscopy image of a major land impression on a bullet fired from a .25 caliber Galesi pistol (original magnification* ×25).

pistol. Again the highlighted region refers to the next photomicrograph in the series. In this case, as in Fig. 2, the higher magnification revealed markings which can allow direct comparison of two bullets.

The striations on the shoulder of the land impressions along the copper-jacketed bullets examined are about 0.15 in. in length along the bullet for the .38 caliber bullets and 0.25 in. in length for the .25 caliber bullets. Within each of these striations are microstriations which can be revealed by a high magnification SEM examination. Figure 4 shows the microstriations taken from the top and bottom of the same striation along the shoulder of the land impressions on the bullet fired from a .25 caliber Galesi pistol. Figures 5*a*, 5*b*, and 5*c* are the microstriations taken from the top, middle, and bottom, respectively, of the shoulder of the land impressions on a bullet fired from a .38 caliber Llama pistol. In each case the microstriations did not have a counterpart set on the same bullet.

Figures 6, 7, and 8 show comparative photomicrographs of the microstriations on different bullets. Figures 6*a* and 6*b* were taken from two different bullets fired consecutively from a .25 caliber Galesi pistol. Figures 7*a* and 7*b* are of the same areas but at a magnification of ×1000 as compared to ×500 for Fig. 6. Figures 8*a* and 8*b* were taken from two different bullets of the set which were fired consecutively from a .38 caliber Llama pistol. The increased depth of field and wider range of magnification of the SEM allows concentration on a small area of detail as can be observed in Fig. 8, which is approximately 0.003 in. in width across the bullet.

The striations on the land impression excluding the shoulders were also examined to determine if consistent markings were present. The markings present were found to exist only along a fraction of the bullet, in most cases being about 0.01 in. in length. Figures 9 and 10 show photomicrographs taken from these areas with Fig. 9*a* taken from Bullet 1

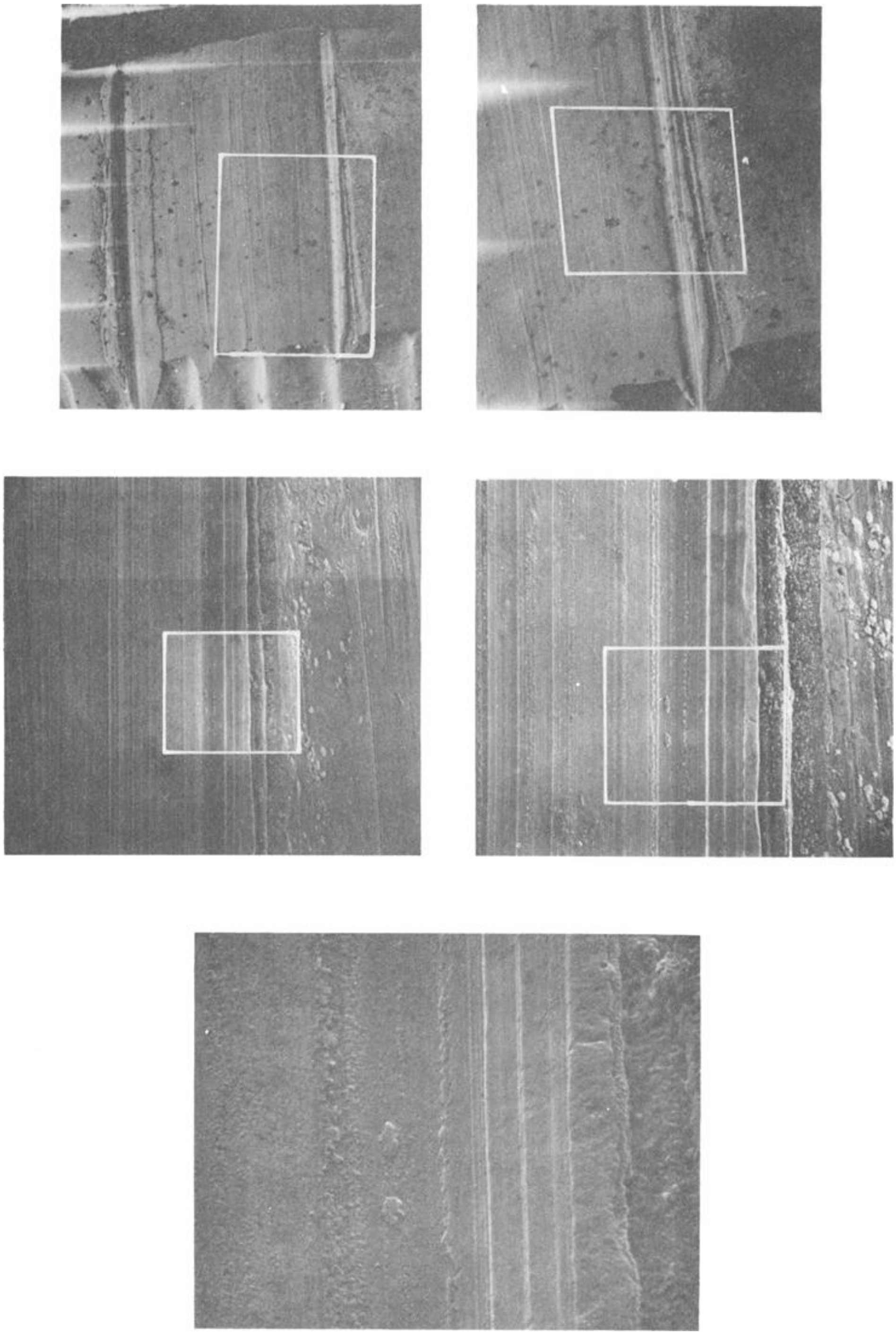

FIG. 2—*Scanning electron microscopy photomicrographs of the same area as in Fig. 1 at original magnifications of* (a) *X30,* (b) *X50,* (c) *X100,* (d) *X200, and* (e) *X500.*

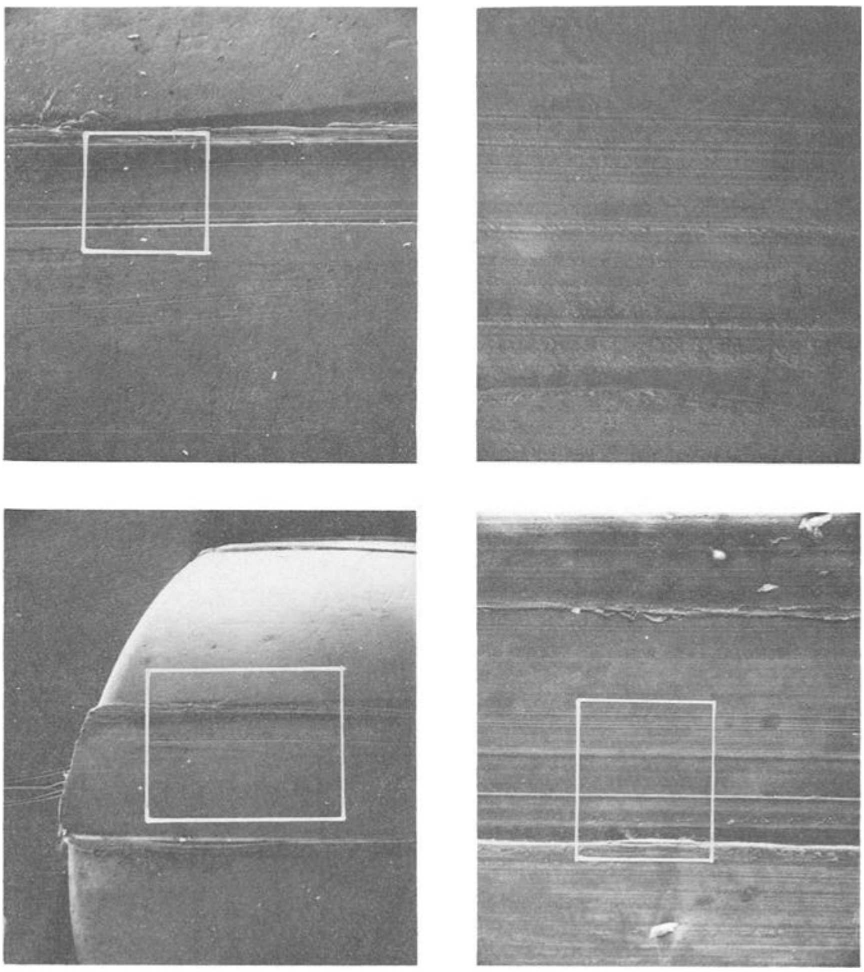

FIG. 3—*SEM photomicrographs of a bullet fired from a .38 caliber Llama pistol at original magnifications of* (a) ×20, (b) ×50, (c) ×200, *and* (d) ×500.

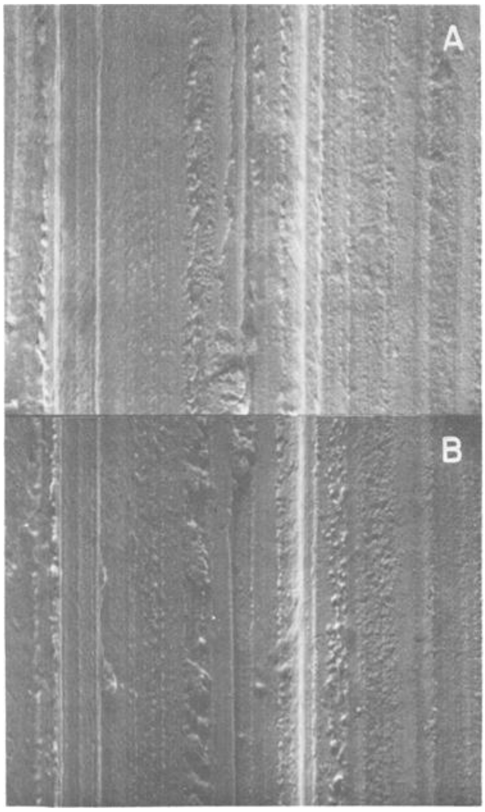

FIG. 4—*SEM photomicrographs of the microstriations within the same striation along the shoulder of the land impression on a bullet fired from a .25 caliber Galesi pistol from* (a) *top of this striation and* (b) *bottom of striation* (*original magnification* ×*500*).

fired from a .25 caliber Galesi pistol and Fig. 9*b* from the second bullet of the set. Figures 10*a* and 10*b* are of two different bullets fired consecutively from a .38 caliber Llama pistol. As in the case of the microstriations, these markings were found to exist only between one set of the striations on one particular bullet.

Contaminant Particles

The chemical composition, surface topography, and shape of the contaminant particles observed in this study showed characteristics which were identifiable with job classifications. The particles from workers' clothing in each industry showed chemical constituents typical of the materials made or processed in that industry. The SEM examination further assisted in the identification and categorization of the particles.

Figure 11 shows a scanning electron micrograph of a particle obtained by vacuuming the clothing of a brass grinding room worker. The surface of the particle is rough and scarred with parallel scratches which are likely to be the result of the grinding process. The X-ray spectrum of the particle showing its chemical construction appears in Fig. 12. The element in greatest concentration is copper, which is indicated by the tallest peak. Zinc, an alloying element in brass, is present in the particles, as well as silicon, sulfur, and other trace elements. The particle was observed in the light microscope and had the

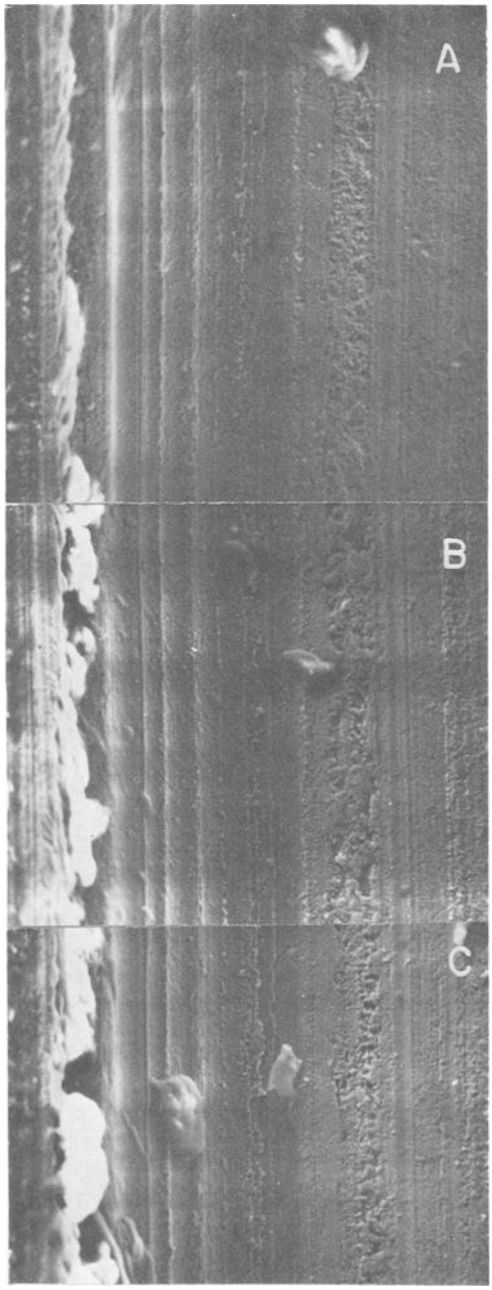

FIG. 5—*SEM photomicrographs of the microstriations within the same striation along the shoulder of the land impression on a bullet fired from a .38 caliber Llama pistol from* (a) *top,* (b) *middle, and* (c) *bottom of the striation* (*original magnification* ×*500*).

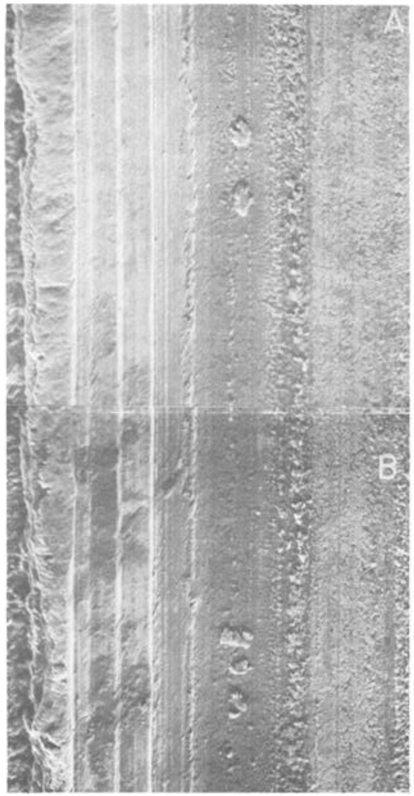

FIG. 6—*SEM photomicrographs of the microstriations along the shoulder of the land impression of two different bullets fired from a .25 caliber Galesi pistol from* (a) *Bullet 1 and* (b) *Bullet 2* (*original magnification* ×*500*).

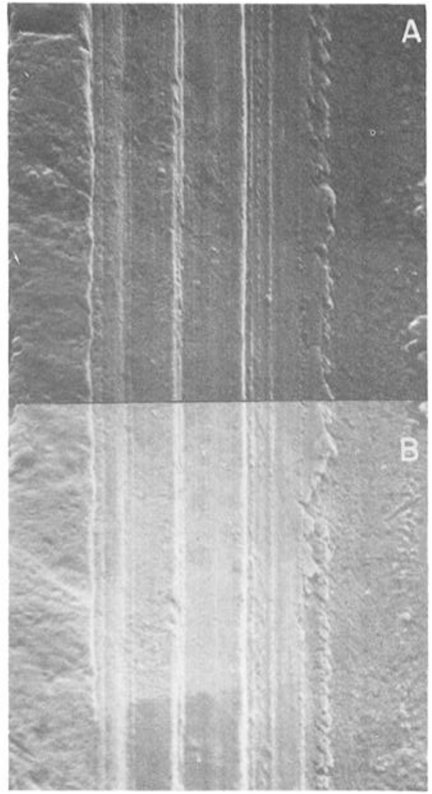

FIG. 7—*SEM photomicrographs of the same areas as in Fig. 3 at original magnification of* ×*1000.*

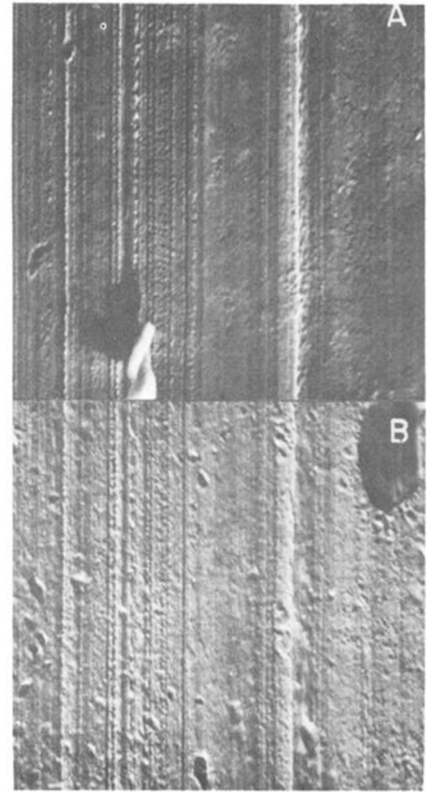

FIG. 8—*SEM photomicrographs of the microstriations along the shoulder of the land impression on two different bullets fired from a .38 caliber Llama pistol from* (a) *Bullet 1 and* (b) *Bullet 2* (*original magnification* ×*200*).

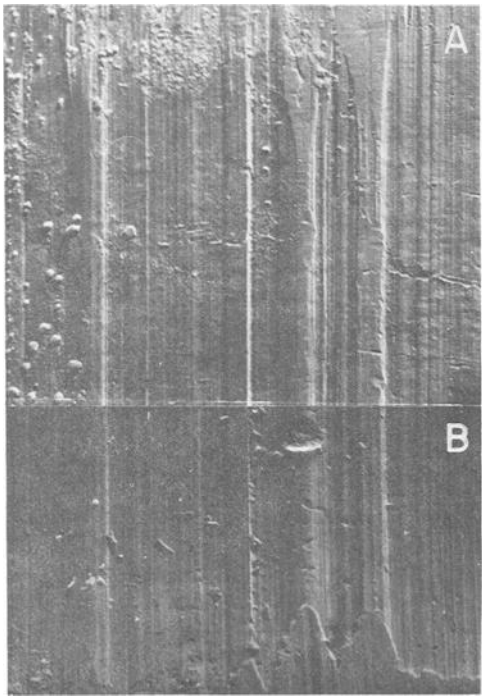

FIG. 9—*SEM photomicrographs of the striations on a land impression on bullets fired from a .25 caliber Galesi pistol from* (a) *Bullet 1 and* (b) *Bullet 2* (*original magnification* ×*200*).

color and reflectivity of metallic brass. Other particles from the same clothing gave nearly indentical results.

Figure 13 shows an SEM micrograph of a particle obtained from a brass foundry worker. The particle is smooth and rounded. The spectrum (Fig. 14) shows an X-ray spectrum for the particle which is nearly identical to that of the particle of the brass grinding room worker (Fig. 12).

The same types of results were obtained from observations of the various iron industry employees. The machine shop workers' clothing contained particles which appeared rough and jagged. Particles from melting and heat treatment workers were smooth and rounded. The chemical spectra showed predominantly the iron (Fig. 15). In particles from the melting and heat treatment workers' clothing, lesser amounts of nickel, chromium, and titanium were typically present. In all of the iron workers, the particles often included small quantities of sulfer and silicon.

The appearance of a typical particle obtained by vacuuming the clothing of a quarry foreman may be seen in Fig. 16. The X-ray spectrum of the particles from this worker contained large quantities of calcium and silicon, which varied in relative concentration from particle to particle. Particles appearing black in the optical microscope typically contained more calcium, and particles appearing white or sandy colored contained more silicon. A typical spectrum is seen in Fig. 17. The particles obtained from the cement plant worker were smaller and uniform in size and texture. These particles gave chemical spectra of calcium and silicon in the same manner as in the quarry. Large quantities of the powdery material were obtained which appeared gray to the unaided eye, but could be resolved into the white particles and black particles by the optical microscope. The clothing of the office worker in the cement plant contained particulate matter within a

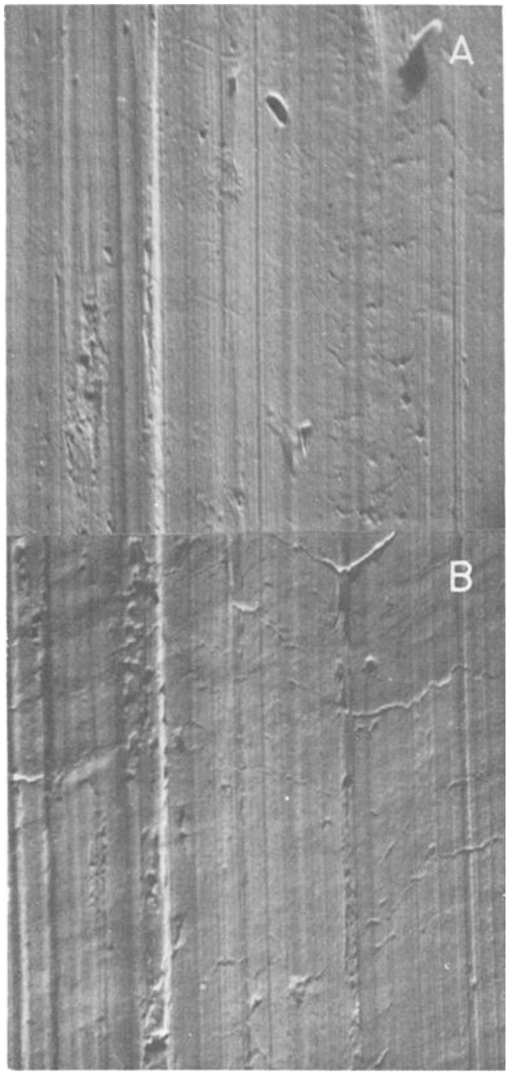

FIG. 10—*SEM photomicrographs of the striations on a land impression on bullets fired from a 38 caliber Llama pistol from* (a) *Bullet 1 and* (b) *Bullet 2* (*original magnification* ×*500*).

wide range of chemical constitutions. Particles typical of the cement workers were present, however.

Workers in the board mill and carton plant showed particles in their clothing which were characteristically smooth, ovoid in shape, and uniform in size. Their X-ray spectra showed no high atomic number elements.

In all cases examined in this study, the vacuuming of the external clothing, such as jackets, shirts, pants, skirts, etc, provided the largest quantity of contaminants characteristic of the job. Brushings of the clothing, pockets, and pants cuffs generally showed smaller amounts of job-related materials and a large amount of debris suspected to be sand, tobacco, thread, dead skin, etc. Similarly, shoes contained particles besides the job-related materials.

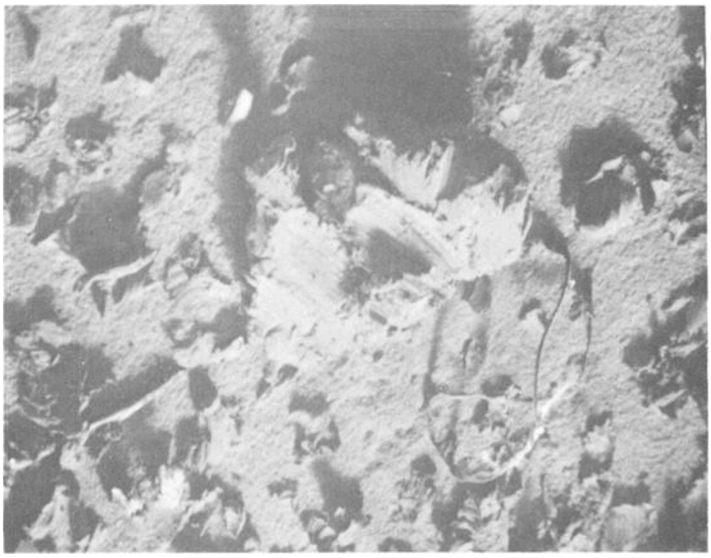

FIG. 11—*SEM photomicrograph of contaminant particles obtained by vacuuming the clothing of a brass grinding room worker. Grinding striae visible on particles. Large particle gave chemical spectrum shown in Fig. 12 (original magnification ×65).*

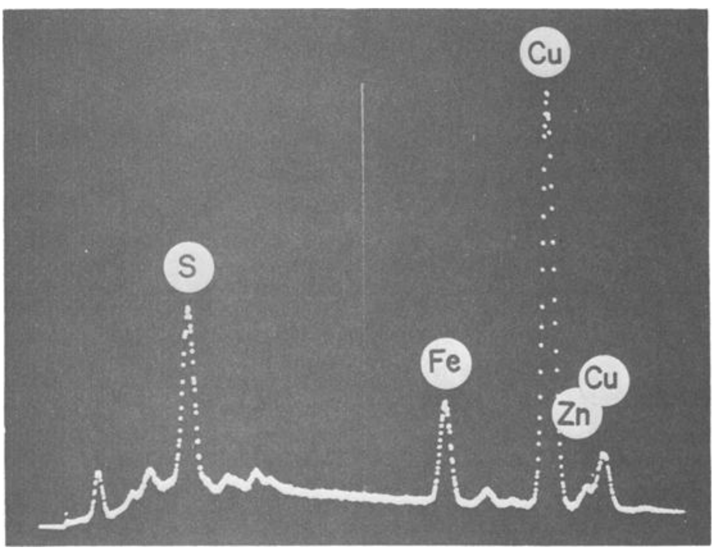

FIG. 12—*Energy dispersive X-ray analysis spectrum (EDS) of the large particle in Fig. 11. Spectrum peak height gives semiquantitative information about the relative amounts of chemical elements contained in the particle. This particle shows copper and zinc expected from brass particle. Sulfur is present as an impurity. Iron and aluminum peaks are due to fluorescence of sample holder and stage.*

Conclusions

The SEM has been shown to be of significant use in the comparative examination of copper-jacketed bullets. The microstriations can be revealed in a manner which is not

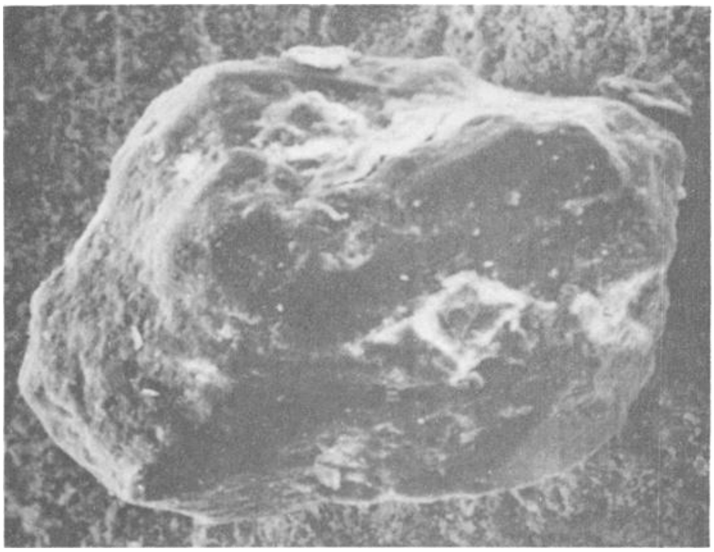

FIG. 13—*SEM photomicrograph of contaminant particle obtained from inside the shoe of a brass foundry worker. Smooth surface is typical of foundry particles and distinguishes them from grinding particles (original magnification ×75).*

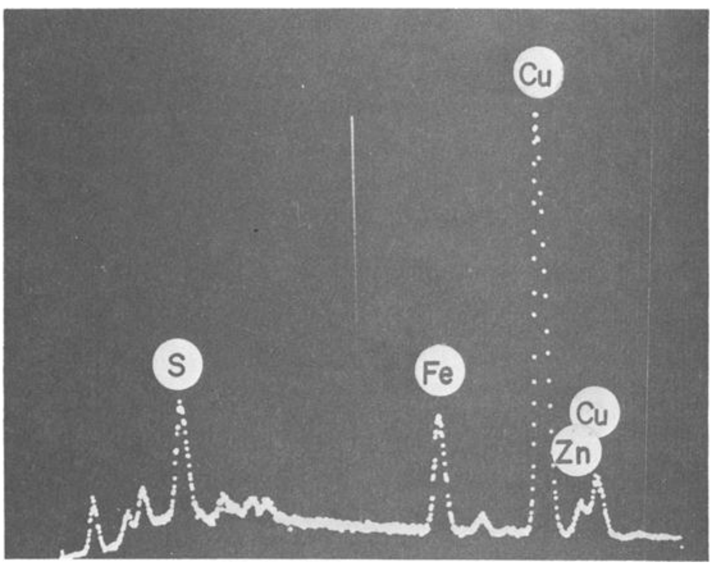

FIG. 14—*EDS chemical spectrum of particle in Fig. 13. It is nearly identical to spectrum in Fig. 12.*

optically possible. The SEM examination of copper-jacketed bullets showed a consistent set of microstriations within each striation and showed a potential means for comparative purposes.

Micrographs from the SEM and chemical compositions provided from X-ray analysis by the EDS should also be of significant use in the identification of very small contaminant particles. Particles found in clothing of workers in various job classifications

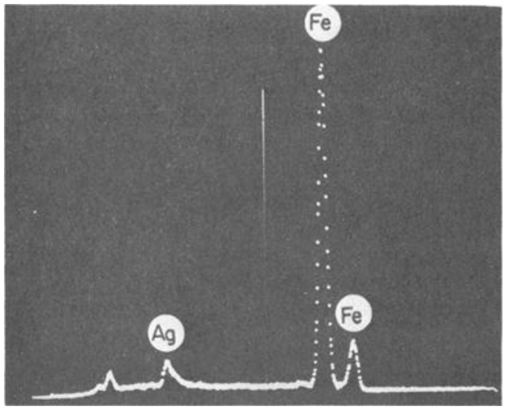

FIG. 15—*EDS chemical spectrum of contaminant particle obtained by vacuuming clothing of an iron machine shop worker. Iron is the only major peak. Silver peak results from fluorescence of silver paint used to adhere particles to stage.*

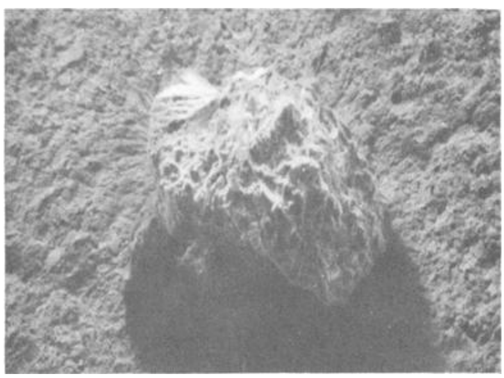

FIG. 16—*SEM photomicrograph of contaminant particle obtained by vacuuming clothing of a quarry foreman. Rough surface morphology is typical (original magnification ×270).*

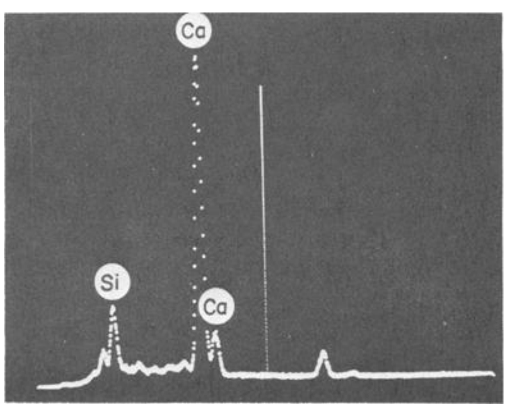

FIG. 17—*EDS chemical spectrum of particle in Fig. 16. Silicon and calcium were present in these particles in varying concentrations, but in far greater quantities than other elements.*

repeatedly showed surface morphologies and chemical compostions which were consistent within the classification and characteristic of the job-related materials.

Summary

The scanning electron microscope (SEM) application to forensic science has been extended to high magnification comparisons of copper-jacketed bullets and to the chemical analysis of contaminants on personal articles such as clothing. The former study relies upon the topographical analysis capability of the SEM while the latter focuses mainly upon the X-ray spectrometer system on the SEM.

The bullet study investigates the comparative quality of striations and the microstriations along the shoulder of the land impression on two bullets. The high magnification study revealed markings on bullets which allowed direct comparison of two bullets such that a determination of possible common origin could be made.

For the investigation of contaminant particles in clothing, samples were collected from workers in various specified local industries. The particles were viewed in light and scanning electron microscopy for color and morphology. An elemental chemical analysis was performed by energy-dispersive X-ray analysis on particles from each collection area (shoe, jacket, etc) from every worker. The spectrum of elements was compared with other collection areas of the same worker and with workers in the other job classifications. Further correlations were drawn between the spectra observed and the elements expected from the known source.

Acknowledgments

The work in this paper was supported by a Federal Grant (FORSEM-New York State Police 633) distributed by the New York State Office of Criminal Justice. The studies were conducted at the Electron Microanalysis Laboratory in the NASA Interdisciplinary Materials Research Center at Rensselaer Polytechnic Institute and at the New York State Police Scientific Laboratory.

The authors express their appreciation to Mr. L. Dillon of the Brown Co., Mr. R. Vanslyke of Atlantic Cement Co., Mr. H. Parkes of Allegheny Ludlum Steel Corp., and Mr. W. White, Jr. of American Valve Manufacturing Corp. for their cooperation in providing samples for the study. The effort of Mr. W. Banta in collecting the contaminant samples is also appreciated.

References

[1] MacQueen, H. R., Judd, G., and Ferriss, S., "The Application of Scanning Electron Microscopy to the Forensic Evaluation of Vehicular Paint Samples," *Journal of Forensic Sciences*, JFSCA, Vol. 17, 1972, pp. 645-658.

[2] Wilson, R. and Judd, G., "The Application of Scanning Electron Microscopy and Energy Dispersive Analysis to the Examination of Forensic Paint Samples," *Advances of X-Ray Analysis*, Vol. 16, 1972, pp. 19-26.

[3] Grove, C. A., Judd, G., and Horn, R., "Examination of Firing Pin Impressions by Scanning Electron Microscopy," *Journal of Forensic Sciences*, JFSCA, Vol. 17, 1972, pp. 659-667.

[4] Grove, C, A., Judd, G., and Horn, R., "Evaluation of SEM Potential in the Examination of Shotgun and Rifle Firing Pin Impressions," *Journal of Forensic Science*, JFSCA, Vol. 19, No. 3, July 1974, pp. 441-447.

[5] Judd, G., Wilson, R., and Weiss, H., "A Topographical Comparison Imaging System for SEM Applications," *Sixth IITRI Symposium*, IIT Research Institute, Chicago, 1973, pp. 167-172.

Materials Division
Rensselaer Polytechnic Institute
Troy, N.Y. 12181